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NOTE.—Mr. E. J. James was unable to attend the meetings of the Committee and declines to sign the report.

May 24, 1901.

RADIO-ACTIVE SUBSTANCES AND THEIR RADIATIONS.

DURING the past five years many physicists, attracted by the freshness of the field and the promise of important discoveries, have turned their attention to the study of the newly discovered radio-active substances. The result has been a rapid increase in knowledge of and interest in the phenomena, until now the main facts are known to all scientists, but, since the knowledge of the subject is increasing so fast, a short review is now and then acceptable and necessary, especially to those whose chief interests lie along other lines. In this article an attempt is made to point out the more interesting features of the subject.

The real discovery of the persistent radiations from the uranium compounds was made by M. Henri Becquerel in 1896. It had been stated by M. Niewenglowski that under the action of sunlight certain phosphorescent salts emit radiations which can penetrate black paper. In testing whether this applies to uranium salts, M. Becquerel discovered to his surprise that with uranium salts exposure to sunlight is unnecessary; uranium compounds are all the time giving off radiations which can pass through opaque bodies and affect a photographic plate on the other side. It was soon found that the uranium radiations discharge electrified bodies in the neighborhood by ionizing the surrounding air after the manner of kathode and X-rays. Naturally, about the first hypothesis was that the radiations are ether vibrations, perhaps of very short wave-length, and many attempts were made to find evidence of reflection, refraction or polarization, with the result that none of these properties nor any of the properties peculiar to wave motion has yet been shown to belong to these radiations.

A few months after the discovery of the uranium radiations Professor Schmidt and Mme. Curie, a Polish physicist working in Paris, independently discovered the radioactivity of thorium compounds. An elaborate study of thorium radiations has since been made at McGill University by Professors Rutherford and Owens.

A greater discovery, however, was in store for Mme. Curie; for observing that many specimens of pitchblende, the principal ore of uranium, were more strongly radio-active than the pure uranium salts, she and her husband attempted a chemical separation of the suspected more active element. The result is well known; they succeeded in isolating two substances having at least 100,000 times the radio-activity of uranium. The first of these substances, which they named polonium, follows the bismuth in the separation from pitchblende. The separation from the bismuth is effected by taking advantage of the fact that polonium sulphide is more volatile than bismuth sulphide. The second substance they named radium. It follows the barium in its chemical reactions, but its chloride is less soluble in water than barium chloride, which affords a means of separation from the barium. Another very active substance has been obtained from pitchblende by M. Debierne. He has named it actinium. Chemically it is closely allied to titanium.

No one of these three substances has been obtained free from impurity, and the amounts obtained are exceedingly small, only a few centigrams from a thousand kilograms of pitchblende.

The spectrum of radium has been carefully examined by M. Demarçay, who assigns to it several new lines, the strongest having wave-lengths 4,683 and 3,814.7, and two bands. No characteristic spectrum has yet been found for polonium or actinium. On account of the small quantities of these substances available, no accurate atomic weight determinations have yet been made, but from what has been done it appears that radium has a higher atomic weight than barium.

At first it was supposed that the uranium itself was the source of the radio-activity of the uranium salts, since often the activity of the compounds seemed to depend on the amount of uranium present, but after the discovery of radium and polonium the radio-active power of uranium began to come under suspicion. Professor Crookes found that often different specimens of the same uranium salt would have very different radio-active strength, which difference in strength could be very little changed by changes in chemical or physical conditions, the strongly active salt remaining so and the less active salt never gaining strength. Suspecting that the radio-activity was due to something other than the uranium, Professor Crookes set about separating this irrepressible element. Such was his success that, starting with active uranium nitrate, he was able to obtain from it uranium nitrate which had no effect on a photographic plate even with an exposure of seven days. At the other end of the separation he had a substance many times as active as the original salt. The best and simplest of several methods of separation makes use of ether as a solvent. The ether dissolves the uranium nitrate and leaves undissolved most of the radio-active substance. This substance Professor Crookes calls UrX, the X testifying to our present ignorance of its real nature. Professor Crookes has also tried to separate the active material from the thorium compounds, but has so far met with only partial success. It seems not unlikely, though, that it may yet be done as completely as in the case of uranium. Meanwhile it is convenient still to speak of uranium and thorium radiations.

PHOTOGRAPHIC AND CHEMICAL EFFECTS OF THE RADIATIONS.

The photographic effect was the one first discovered and it remains the most delicate test for radio-activity, for the effect is cumulative, and the exposure may be made as long as desired. Any one can obtain very good radiographs from any of the ordinary uranium salts by using rapid dry-plates and an exposure of two days, while visible effects can be obtained with a much shorter exposure. Polonium and radium affect a photographic plate in a few minutes if sufficiently close to it. Even with a distance of a meter between the radium and the plate, radiographs have been obtained after a few days' exposure. These are very sharp, showing thus the rectilinear propagation of the radiations. Polonium radiations are so rapidly absorbed by the air that no effect is produced with a greater distance than a few centimeters.

Under the action of the radium radiations glass takes a permanent brown or violet tint. The haloid salts of the alkali metals become colored just as under the action of the X-rays. Paper is sometimes discolored and under certain conditions ozone may be formed in the neighborhood of the very active substances. Barium platino-cyanide is colored brown.

The action of the radium rays on the skin is the same as that of the X-rays. At first there is a slight reddening of the skin, but after three or four weeks' exposure severe inflammation sets in.

FLUORESCENCE.

Most of the substances that show fluorescence under the action of ultra-violet light or the X-rays also fluoresce under the action of the radium radiations, while those that fluoresce under ordinary light do not fluoresce under the radium radiations; but there are numerous exceptions to these rules.

It is a very interesting fact that when freshly prepared the radium salts are faintly self-luminous, and this property seems to be retained as long as the salt does not absorb moisture. It is this property that has excited much of the popular interest in the radium salts, for it is a case of the longed-for light without heat. In fact, it is light with no apparent source of energy whatever. If radium chloride ever becomes cheap we may be given an opportunity to court fortune by investing in preferred stock of some 'International Radium Illuminating Company.' Just at present gold is dirt cheap in comparison with these radium salts. The self-luminescence is due to the fact that under the action of its own rays either the salt itself, or some of the unavoidable impurities, fluoresces.

Some of the tissues of the eye fluoresce under the radium rays, so a sensation of light is felt when some of the salt is brought before the closed eyelids or placed on the temple.

IONIZATION OF GASES.

Any gas traversed by the Becquerel rays, as Mme. Curie has named the new radiations, is made capable of conducting electricity. This conductivity is of the same nature as that produced in gases by the kathode and X-rays. According to the accepted hypothesis, the positive and negative particles or ions of the gas are knocked apart by the radiations, and the motion of these free charged ions when directed by an electric field constitutes the electric current. If an ionized gas is left to itself the positive and negative particles soon reunite, and, in fact, the reuniting process goes on all the time in proportion to the number of free ions in the gas, so that under any given intensity of ionizing radiation a condition of equilibrium is soon reached in which the reuniting goes on as fast as the ionizing. Since the amount of ionization may be measured by measuring the electrical conductivity of the gas, this affords a convenient means of comparing the relative strengths of radio-active substances, and one which is much more rapid and accurate than the photographic one. It is by no means certain, however, that the radiations most effective for ionization will therefore produce most effect on a photographic plate. Ionization is proportional to the absorption of the radiations by the gas, so that if a bit of radio-active substance be placed between two metal plates a greater current may be sent between them when they are two centimeters apart than when they are only one, the greater thickness of the air in the first case absorbing more of the radiations.

An ionized gas is in many respects similar to an ordinary liquid electrolyte, and Lord Kelvin has shown that when a plate of copper and a plate of zinc are connected by a wire and the air between the plates exposed to radiations from uranium compounds, a current flows through the connecting wire just as if the plates were immersed in a liquid electrolyte. It has recently been shown that the Becquerel rays decrease the resistance of selenium, just as light and the X-rays do.

PENETRATING POWER.

The radiations from the various substances are not at all homogeneous, some being very penetrative, others being easily stopped by any substance. Polonium radiations, while intense, are of the non-penetrating kind, being stopped by even the thinnest metal foil. Uranium radiations, and therefore Crookes' UrX radiations, are much more penetrating, passing through metals, glass and in fact all substances, but with considerable loss of intensity. Thorium compounds emit radiations of at least two very different penetrating powers, one part only feebly penetrating, another as penetrating as the UrX radiations. Radium and actinium also emit both penetrating and non-penetrating rays, some of the radium rays being the most penetrating of all. Screens of sheet metal act as sieves for the rays, soon cutting off the less penetrating rays and allowing the more penetrating kind to go through with but little diminution in intensity. One sheet of tin, 0.0025 mm. thick, transmitted 44% of the radiations from one radium specimen, two sheets of the same thickness transmitted 31%, and 15 sheets 15%. A sheet of glass 0.16 mm. thick transmitted 26%, and ten plates 16%. Aluminum 0.16 mm. thick transmitted 28%, six sheets 16%. On account of the non-homogeneity of the radiations it has been very difficult to determine the law of absorption, but it appears that for the rays of the most penetrating type, at least, the absorption is proportional only to the density and thickness of the absorbing screen, the kind of material, whether platinum, paper, glass, air or other substance, making but little difference. Because some of the less penetrating rays are absorbed by the salt itself, there is a larger proportion of the very penetrating rays in the radiations from a thick layer of the salt than in those from a thin layer.

DEFLECTION IN A MAGNETIC FIELD.

Several experimenters discovered about the same time that some of the Becquerel rays are affected by a magnetic field. This brought out strongly their resemblance to the kathode rays, and further experimenting proved that if a beam of radium radiations is made to pass through a magnetic field which is perpendicular to the direction of the beam, then the beam is deflected just as a beam of kathode rays would be, that is, just as a stream of negatively charged atomic projectiles would be deflected. This fact furnished the basis for the present accepted hypothesis, namely, that the deviable rays consist of a stream of rapidly moving particles, charged with negative electricity. The deflection in a magnetic field gives further proof of the non-homogeneity of the radiations. The experiment is as follows : A vertical beam is obtained by placing the radio-active salt at the bottom of a narrow hole in a block of lead, which is then placed on a horizontal photographic dry-plate or a fluorescent screen, in the horizontal field of a large electro-magnet. When the magnet is energized the vertical beam of rays is deflected in a direction always perpendicular to its direction of propagation, and also perpendicular to the magnetic lines of force, so that it is finally bent over until it falls upon the plate or screen. The impression produced is not a spot, but a band or magnetic spectrum, which could not be the case if the beam were composed of homogeneous radiations. According to the electrified-projectile hypothesis this can be explained by saying that the particles do not all have the same velocity, in which case those having the highest velocity would be the least deflected. This view has support in the fact that of the deviable rays, the least deviable are the most penetrating, as we should expect from the higher velocity of the particles. Becquerel found that for the rays from a sample of radium the product of the strength of the field into the radius of curvature of the path varied from 350 to 3,000.

There are, however, certain rays that are not deflectable in a magnetic field, and these are of the least penetrating kind, which, according to the charged-particle hypothesis, should, on the contrary, be most deflected by the field. A satisfactory hypothesis as to the nature of these non-deflectable, non-penetrating radiations has not yet been put forth. Perhaps they consist of particles of much larger mass than those of the deflectable rays. M. Villard finds also in the radium radiations a small proportion of very penetrating, non-deflectable rays, quite similar to the X-rays.

ELECTROSTATIC EFFECTS.

Now a stream of charged particles deflectable by a magnetic field should also be deflected by an electrostatic field. This is found to be the case. Furthermore, a shower of negatively charged particles ought to impart a negative charge to an insulated conductor. Of course in this case air would not act as an insulator, for it becomes a conductor under the action of the rays. M. and Mme. Curie got around this difficulty by insulating a conductor with a thin layer of wax over its surface, then exposed it to radium radiations and found that it became highly charged negatively. Insulating some of the radium salt in the same manner with wax, they found that it became highly charged positively, a beautiful corroboration of the theory that there is a separation of the atomic particles with their charges. If, as now seems almost certain, the negatively charged part of the atom has a mass only a small fraction, a thousandth perhaps, of that of the positive part, it is very reasonable that the negative particles would be the ones to be shot out in case of interatomic commotions. The rate of charging in the experiment was about 4×10^{-12} amperes per sq. cm. of the radium salt.

VELOCITY, MASS AND ENERGY OF THE RADIATIONS.

The velocity of a charged particle and the ratio of the charge to the mass may be found by comparing its path in a magnetic field with its path in an electrostatic field, Then assuming the charged-particle hypothesis it should be possible to calculate the velocity of the particles in the deflectable rays from the radio-active substances. This has been done by M. Becquerel. The curvature of the path in the magnetic field can be measured without much difficulty, but the deflection in the electrostatic field is very small. The difficulty of the experiment is also increased by the complex character of the radiations, making it uncertain if rays of just the same kind are being observed in the two fields. Some confidence, however, must be placed in the results, though they give for the velocity of the particles an astounding figure, about half the velocity of light. How from a quiet, peaceful bit of white salt particles can be shot off with such a velocity as this remains for explanation. The ratio of the charge to the mass of the particles is of the same order as in the case of the kathode rays, another evidence that the atomic charges are invariable and inseparably connected with the particles.

By measuring the rate at which a charge is imparted to a conductor, and then using the values of the velocity and of the ratio of the charge to the mass determined as above, the kinetic energy per second of the particles emitted may be calculated. For a sq. cm. surface of a very active radium preparation it has been found to be 5.1 ergs per second, or five ten-millionths of a watt. The mass of the particles, calculated from the same data, is exceedingly small, the loss from a sq. cm. of surface being something like a milligram in a thousand million years. M. Becquerel observes that it is of the same order as the evaporation of certain odorous bodies.

Professor Rutherford and Mr. McClung made last year some interesting experiments on the energy required to produce ionization of gases by kathode and X-rays. Assuming that the same energy is required to produce ionization by the Becquerel rays, they estimate that a sq. cm. surface of a thick layer of uranium oxide gives off energy at a rate not less than 10^{-11} calorie per second, which is sufficient to raise the temperature of 1 gram of water 1° C. in 3,000 years. In the case of radium, 100,000 times as active as uranium oxide, the energy given off is not less than 3,000 calories per year for a gram of substance. This value for the energy is 40 or 50 times as large as the value mentioned above, obtained by the other method. That the amount of energy concerned is so small emphasizes the extreme delicacy of the photographic and ionization tests.

SECONDARY RADIATIONS.

X-rays impinging on some substances induce secondary radiations, and it was soon found that the Becquerel rays also possess this power, with the important difference that the secondary radiations induced by the Becquerel rays continue after the action of the primary rays has ceased, which is not the case with those induced by the X-rays. These secondary radiations affect photographic plates and ionize gases. The radium preparations are the most active in producing secondary radiations, and the effect is produced equally well in the case of such different substances as platinum, zinc, bismuth and even paper. Up to a certain limit the intensity of the secondary rays increases with the time of exposure to the radium; after the removal of the radium the intensity gradually weakens, disappearing altogether after some hours. The source of the secondary rays was thought to be a fine dust which escapes from the radium and settles on neighboring bodies, but it cannot be removed by washing, and the radium rays have the power of imparting it even after passing through metal screens. It seems too that this power of emitting radiations may even be imparted to gases. A number of substances may be made strongly radio-active by precipitation from solutions containing small amounts of the most active substances, and several times these temporarily active substances have been mistaken for compounds of new elements. It is not yet known to what extent the secondary radiations are like the primary, for their intensity is so small that a comparison is difficult.

Thorium oxide gives off a remarkable vapor or 'emanation' which causes a strong secondary radio-activity. This emanation can pass through paper and even very thin metal. It gradually diffuses itself throughout the air and is carried about by air currents. Air containing the emanation retains its electrical conductivity for as long as ten minutes after the thorium oxide is removed, though ordinary ionized air loses its conductivity in a few seconds. The emanation is not removed from the air by drawing it through wool or bubbling it through water or sulphuric acid. Any substance charged with negative electricity collects and concentrates the emanation, becoming very radio-active after a few hours in the presence of thorium oxide. Sand-papering or treatment with sulphuric acid removes the emanation from a platinum wire on which it has been concentrated. On afterwards evaporating the acid a radio-active residue may be obtained. The thorium emanation much resembles a fine radio-active dust.

NATURE OF THE RADIATIONS AND SOURCE OF THEIR ENERGY.

We may say then that for one component of these complex radiations a satisfactory explanation is offered. This component is of the same nature as the kathode rays, and consists of a rapidly moving stream of minute material particles each having its charge of negative electricity.

Another component is similar to the X-rays, and is probably a phenomenon of the ether rather than of ordinary matter. Perhaps this component is produced by the action of the first component, as the X-rays are produced by the action of the kathode rays. For the rest no satisfactory explanation has been given. Many of the secondary effects seem to result from a fine dust emitted from the radio-active substance. Possibly there is only a single primary radiation, the rest being secondary effects, as the kathode rays generate the X-rays and these in turn generate their complex secondary radiations.

The chemical nature of the radio-active substances or elements is still little understood, nor is it surprising when one considers the difficulty of working with substances occurring in such minute quantities as these. Only one new element, radium, is definitely established. Hofmann and Strauss thought they had isolated another new radio-active element, but while still claiming the new element, they now admit that it is not radio-active.

The question of the source of energy in these radiations is yet unanswered. Is the energy potential in an unstable molecular or atomic structure, or is it supplied continuously by outside sources? In the first case, how long will the energy last? In either case, is it a property that matter in general may under proper conditions assume, or is it, as it seems, restricted to a very few peculiar elements? Heat or cold, high or low pressure, has little influence on the emission of the rays. Mme. Curie once put forth the hypothesis that perhaps the radiation is induced in the radio-active elements by a sort of transcendental radiation more penetrating than the X-rays and pervading all our space. Professor Geitel found that if so the exciting radiations penetrate easily hundreds of yards of rock, for radium was still active at the bottom of the deepest mine to which he had access. Finally, the study of the radio-active substances will surely lead to a better knowledge of that which is the subject of much of the physical research of to-day, the intimate structure of matter.

GEO. B. PEGRAM.

COLUMBIA UNIVERSITY,
June 21, 1901.

THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

THE following have completed their membership in the American Association for the Advancement of Science during the month of June.

Dr. Francis E. Abbot, Author, 43 Larch Road, Cambridge, Mass.

Ernest Kempton Adams, Scientific Investigator, 455 Madison Ave., New York, N. Y.

Harry Alexander, Elec. and Mech. Engineer, 18 and 20 West 34th Street, New York, N. Y.

E. B. Alsop, Metallurgy and Engineering, 541 Wood Street, Pittsburg, Pa.

James I. Ayer, Electrician, 5 Main Street Park, Malden, Mass.

Ralph Baggaley, engineer, Pittsburg, Pa.

Daniel Moreau Barringer, Geologist and Mining Engineer, 460 Bullitt Building, Philadelphia, Pa.

Professor Walter B. Barrows, Prof. of Zoology, Agricultural College, Michigan.

Francis Bartlett, 40 State Street, Boston, Mass.

James Newton Baskett, Author-Zoologist, Mexico, Mo.

Rev. John Mallery Bates, Botany, Callaway, Neb.

Dr. Henry Harris Aubrey Beach, Physician, 28 Commonwealth Avenue, Boston, Mass.

Professor Arthur E. Beardsley, Prof. of Biology, State Normal School, Greeley, Colo.

Bernhard Arthur Behrend, Civil and Elec. Engineer, Station H, Cincinnati, Ohio.

August Belmont, 23 Nassau Street, New York City.

Charles W. Bennett, Geologist, Coldwater, Mich.

Dr. Augustus C. Bernays, Specialist in Embryology, Anatomy and Surgery, 3623 Laclede Avenue, St. Louis, Mo.

Solomon H. Bethea, United States Attorney, Chicago Club, Chicago, Ill.

Dr. Leslie D. Bissell, Physics, Hotchkiss School, Lakeville, Conn.

Dr. John B. Blake, Physician, 302 Beacon Street, Boston, Mass.